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Andersen, Lill; Hansen, Henrik

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Human capital, technological progress and growth in developing countries

by

Lill Andersen and Henrik Hansen[1]
Institute of Food and Resource Economics
University of Copenhagen
Denmark
E-mail: lth@foi.dk

Abstract

In a model of imitation it is demonstrated that an economy's technological development is positively correlated with its human capital stock implying that a change in education affects the growth rate of GDP both directly through its impact on output and indirectly through its impact on the ability to adopt new technologies. In addition to human capital, idiosyncratic characteristics determine imitation activity such that more education as well as better institutions, a more business-friendly government policy and lower technology barriers boost the technological development. The policies may, however, have very different effects on income per capita in the short and medium run and on the technological capacity limit.

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1. Introduction

In a model with focus on imitation of new products with varying productivity levels we illustrate that the human capital stock of a country and idiosyncratic characteristics combine to determine the maximal attainable productivity level. Countries with identical human capital stocks may, therefore, follow different growth trajectories depending on idiosyncratic characteristics that affect the incentives to engage in imitation activity. And countries that follow a growth trajectory characterised by a steady state with relative low average productivity may do so due to the existence of a low-quality labour force or due to the existence of institutions of a low quality, bad governance, high technology barriers or other idiosyncratic characteristics.

The framework suggests that policy measures must be carefully chosen to optimise growth because catching up with the world technology leader requires both human capital and institutions and government policies that provide incentives to engage in imitation activity. There is a danger that a country may over-invest in one object in the sense that it would stimulate growth more if it were to spread its investments. For example, continuous investments in education should preferably go hand in hand with improvements in the quality of the country's institutions, more business-friendly government policies and other characteristics increases the incentives to imitate.

Furthermore, by identifying the channels through which human capital may affect income growth we are able to identify the dynamic effects of a change in education policy. Our results suggest that the timing of the effects of investments in education may be important to take into account. This is because an increase in the human capital stock affects the income of countries both directly as a productive input and indirectly through its impact on the ability to imitate new products. The only effect that appears in the short run is the increase in output from manufacturing due to the input expansion but in the longer run there is also a productivity effect as goods with larger productivity are imitated. Moreover, even though there may be positive effects on per-capita GDP of both an increase in education and a lowering of the costs of imitation in the longer run, the two policies may have very different effects on income in the short and medium term and on the technological level in the long run. This is because the latter policy elicits a reallocation of resources away from manufacturing into imitation activity which impact negatively on income in the short run but in the longer run it increases both the per-capita GDP level and the technological level.

Our paper complements the literature on the link between human capital, productivity and income growth. Nelson and Phelps (1966), Benhabib and Spiegel (1994, 2005) and Bils and Klenow (2000) assume a link from human capital to technology such that human capital influences productivity growth. Here we demonstrate the existence of such a relationship in a model of imitation: a larger human capital stock enables entrepreneurs to imitate technologies with higher productivity, thereby increasing the average productivity level in the economy. Our framework highlights the dynamic effects and the complementarity of education policy and policy measures aimed at affecting the incentives to imitate such as institutions and government policy. If a country manages to increase the human capital stock it will boost income but the development possibilities are limited if the incentives to imitate are repressed due to low-quality-institutions, bad governance or high technology barriers. It is, therefore, important to develop education facilities, institutions and government policy simultaneously.

The paper is organized as follows. In section 2 we provide some background information. Then in section 3 we describe the theoretical framework. In section 4 we explore its implications regarding the relationship between human capital, productivity and growth in the short and long run. In section 5 we consider policy implications and conduct numerical simulations to illustrate the workings of the model further. The last section contains concluding remarks.

2. Background

In the literature on human capital and economic growth three channels through which education may affect growth are identified:

- Education increases the human capital inherent in the labour force which increases labour productivity in manufacturing and, hence, output growth – at least temporary (Mankiw et al., 1992; Lucas, 1988);

- Education increases the innovative capacity of the economy and the new knowledge, new technologies and/or new products promotes growth (Romer, 1986, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992, 1998);

- Education facilitates the diffusion and transmission of knowledge needed to successfully implement new technologies devised by others which promotes growth (Nelson and Phelps, 1966; Benhabib and Spiegel, 1994, 2005).

Growth accounting analyses of the Solow growth model (Solow, 1956) indicates that physical capital accumulation can explain only a fraction of the variation in growth rates across countries while the rest is attributed to technological progress (Solow, 1957; Maddison, 1987). Incorporating human capital as an input into the production function, Mankiw et al. (1992) find that schooling is a significant determinant of GDP per capita and that physical and human capital accumulation and population growth explain almost 80 percent of the observed cross-country variation in per-capita income. Recent empirical evidence indicates, however, that the positive relationship between human capital accumulation and economic growth implied by the framework of Mankiw et al. is not robust. Benhabib and Spiegel (1994) find that the growth of years of schooling (using human capital stock estimates by Kyriacou, 1991) enters negatively and insignificantly in a cross-section of countries. Further, Pritchett (2001) reports a negative estimated impact of human capital growth on the growth of GDP per worker in less developed countries (using two data sets: Barro and Lee (1993) which is based on educational attainment and Nehru et al. (1995) who use the perpetual inventory method to accumulate enrolment rates). Temple (2001) estimates various specifications of the link between education and economic growth and concludes that[2]"…the aggregate evidence on education and growth, for large samples of countries, continues to be clouded with uncertainty."

An alternative view of the role of human capital is that it affects technological development and total factor productivity (TFP). This hypothesis was originally proposed by Nelson and Phelps (1966) who suggested that the rate at which the gap between the technology frontier and the current level of productivity is closed depends on the level of human capital. In technology-based growth models where development of new or better products is the ultimate source of growth, human capital is a facilitator of technological development. Typically, these models imply that technological development is positively related to the stock of human capital in the economy. Many cross-country growth regression analyses find a positive correlation between initial human capital and subsequent per capita income growth (e.g., Barro and Sala-i-Martin, 2004). Benhabib and Spiegel (1994, 2005) find a positive role for human

[2] Temple (2001) p. 916.

capital when the growth rate of total factor productivity is allowed to depend on a nation's human capital stock. Bils and Klenow (2000) investigate whether the correlation between initial human capital and subsequent income growth works through human capital accumulation taking into account a possible link from human capital to technology. Using calibration techniques they find little evidence of an effect from human capital growth on technological development. On the contrary, they find evidence of reverse causality, i.e., that income growth generates human capital accumulation.

One reason why it is difficult to reach consensus regarding the relative importance of different mechanisms by which education affect growth may be measurement error in cross-country data. Krueger and Lindahl (2001) criticize both the Kyrtiacou (1991) and Barro and Lee (1993) data sets because they are based on mismeasured enrolment rates and because they contain little information. De la Fuente and Doménech (2001, 2006) also find that these data sets as well as other sets contain substantial measurement error. They construct a revised set of estimates for 21 OECD countries based on an extended set of information on educational attainment in each country and estimate a significant schooling coefficient when they use this data set in growth regressions. Cohen and Soto (2007) construct a new data set for years of schooling in 95 countries. They make use of information on educational attainment by age to build the average years of schooling in a country and avoid censuses based on different classification systems of education to keep the series consistent for a particular country over time. They estimate a significant positive coefficient for schooling in cross-country growth regressions based on the Mincerian definition. Hanushek and Kimko (2000), Wößmann (2003) and Hanushek and Wößmann (2008) criticize the literature on education and growth for neglecting qualitative differences in education. They recommend focusing on how much students have learned while in school in stead of counting how long they have sat in school. Empirical evidence suggests a significant positive effect of the quality of schooling on economic growth using international tests of students' performance in cognitive skills as a proxy for the quality of education.

Another way to progress in our understanding of the effects of human capital on economic growth is to more carefully examine the channels through which such effects could work. This is what we attempt in this paper. Neither Benhabib and Spiegel nor Bils and Klenow formally derive the link from human capital to technology. Rather, they assume that there is a link either between the technological development and the level of human capital (Benhabib and Spiegel) or between the level of technology and the level of human capital (Bils and Klenow). In this paper we set up a framework where human capital has two alternative uses: as an input into the production of output and an input into imitation activity. An increase in the human capital stock, therefore, affects the income of countries both directly as a productive input and indirectly through its impact on the ability to imitate new products. The only effect that appears in the short run is the increase in output from manufacturing due to the input expansion but in the longer run there is also a productivity effect as goods with larger productivity are imitated. As in models of innovation-based growth our framework suggests that the allocation of human capital affects the development of technology and the growth rate of per capita GDP. But while Romer and others emphasize the link between product variety and average productivity, we assume that different products are associated with different technological levels and that it requires more human capital to imitate and adopt high-technology goods than to imitate and adopt goods of a lower technological sophistication. This feature generates a link between the size of the human capital stock and countries' ability to imitate more advanced products and gain productivity and income growth.

The idea that different products are associated with different productivity levels has been employed in the part of the endogenous growth literature that emphasizes vertical product development (Grossman and Helpman, 1991; Aghion and Howitt, 1992, 1998). Contrary to these models our framework does not assume creative destruction. Even though adoption of new products with higher productivity decreases the demand for existing products they do not drive out existing products from the market.

Other recent attempts to model the channels through which human capital may affect economic growth include Vandenbussche et al. (2006) and Ciccone and Papaioannou (forthcoming). Assuming that technological progress is the result of both imitation and innovation, Vandenbussche et al. demonstrate that human capital may play a different role at different stages of development. Because the tasks of imitation and innovation requires different types of human capital the growth-enhancing impact of skilled human capital (holding the total level of human capital constant) increases with a country's proximity to the frontier, while the growth-enhancing impact of unskilled labour decreases with the proximity to the frontier. For a sample of 19 OECD countries they find evidence that skilled human capital significantly matters for technological progress while unskilled human capital contributes little to technological improvement.

Ciccone and Papaioannou combine the idea of different types of human capital with an assumption of different efficiency growth of the two types of human capital (increasing in the gap between country efficiency and world frontier efficiency as in Nelson and Phelps and Benhabib and Spiegel). Assuming the existence of two industries that differ in terms of their skill intensity, Ciccone and Papaioannou demonstrate that an increase in human capital may affect the relative production differently through the input effect and the technology adoption effect. They also show that an increase in the efficiency growth of high human capital at the world frontier implies that countries that are relatively abundant in human capital increases their relative production of the skill intensive good compared to countries with less human capital. Empirically the authors find that countries with higher initial levels of schooling experiences faster growth in more compared to less schooling-intensive industries in the 1980's and 1990's where new technologies are thought to be more skilled-labour augmenting than the technologies of the 1950's and 1960's.

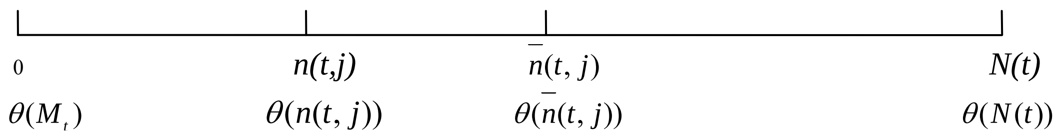
Our emphasis on the interplay between human capital and idiosyncratic characteristics such as institutions derives from the part of the growth literature that debates the fundamental causes of growth. Hall and Jones (1999) find that differences in institutions and government policies account for much of the difference in capital intensity, human capital per worker, productivity and, hence, output per worker across countries. Acemoglu et al. (2001) confirm this result using differences in European mortality rates at the time of colonization as instrument for current institutions. They, therefore, conclude that institutions that provide the incentives for individuals and firms to invest in human and physical capital are the fundamental sources of growth. Glaeser et al. (2004) claim, however, that European mortality rates are more highly correlated with human capital than with current institutions, thereby questioning the validity of the instrument. Using different measures of institutions they find that human capital is the most important fundamental source of growth. Glaeser et al. (2007) develop a framework where education encourages democracy because it raises the benefits of political participation. Baten and van Zanden (forthcoming) show that human capital formation measured by book production per capita *and* growth enhancing institutions both had a strong positive effect on economic performance in the centuries before 1800.

3. Theoretical framework

The model focuses on imitation of new goods as the engine of technological development where the goods are associated with different productivity levels. The invention of new goods takes place abroad and is not modelled. Hence, we consider a group of developing countries who imitate goods invented in technologically more advanced countries. These countries do not invent new goods themselves but they may devote resources to the task of imitation in order to copy and adapt goods invented abroad.

At time *t* there exist $N(t)$ differentiated goods in the world. Each good is identified by a certain productivity level θ, representing the units of output generated by a given amount of inputs. Goods are aligned on a continuum such that higher-ranked goods entail higher productivity. The productivity level grows at a constant rate g_θ per good implying that good i is associated with a productivity level of $\theta(i) = \theta(0)e^{g_\theta i}$ where $\theta(0)$ is predetermined.

Consider developing country *j*. The range of goods that this economy is capable of copying and adapting in period *t* is given by a continuous interval between *0* and $\bar{n}(t,j)$. The maximum level of sophistication $\bar{n}(t,j)$ is determined by a country-specific imitation parameter and the stock of human capital in the economy. The range of goods that the economy produces at time t^* belongs to $[0, n(t,j)]$ where $n(t,j) \le \bar{n}(t,j) < N(t)$. Each of these goods is associated with a unique productivity level. Hence, $n(t,j)$ is the number of goods that is produced at time *t* and $\theta(n(t,j))$ is the productivity level of the most productive good at time *t*:



Henceforth we consider a single developing country. Therefore we drop the country index.

Households

The economy consists of a number of identical infinitely lived households. The representative household maximizes utility over an infinite horizon subject to an intertemporal budget constraint. Households like diversity in consumption and we adopt the Dixit-Stiglitz (1977) specification which implies a constant and equal rate of substitution between every pair of goods.

$$U(t) = \int_t^{\infty} e^{-\rho(\tau - t)} \log\left[\left(\int_0^{n(t)} x(\tau, j)^{\alpha}\, dj\right)^{\frac{1}{\alpha}}\right] d\tau$$

where $\rho > 0$ is the constant subjective discount rate, $x(t,i)$ is consumption of good no. *i* at time *t*, $n(t)$ is the number of differentiated goods available for consumption at time *t* and $\alpha \equiv (\varepsilon - 1)/\varepsilon$ where $\varepsilon > 1$ is the elasticity of substitution between any pair of goods.

Households are endowed with an exogenous stock of human capital and income is generated through the supply of human capital and returns to its financial wealth. Households can freely borrow and lend at the instantaneous interest rate *r(t)*. These assumptions imply the following budget constraint:

$$E(t) + \dot{B}(t) = w(t)H(t) + r(t)B(t)$$

where $E(t)$ is the household's nominal spending in period *t*, $B(t)$ is the financial wealth, $w(t)$ is the wage rate per unit human capital, and $H(t)$ is the stock of human capital.

Solving the representative households' problem implies the following first order conditions:

(1) $$x(t,i) = \frac{E(t)}{P(t)} p(t,i)^{-\varepsilon}$$

(2) $$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho$$

where equation (1) determines the demand for each type of good and (2) is the Keynes-Ramsey rule. $p(t,i)$ is the price of good *i* and

$P(t) \equiv \int_0^{n(t)} p(t, j)^{1-\varepsilon} dj$ is a price index.

We apply the normalization suggested by Grossman and Helpman (1991) that households' nominal spending is normalized to one in each period of time. Then equation (1) is rewritten as

(1') $$x(t,i) = \frac{1}{P(t)} p(t,i)^{-\varepsilon}$$

and equation (2) implies that the interest rate equals the discount rate:

(2') $$r(t) = \rho .$$

Goods production

In order to focus on the interaction between human capital and the production structure in determining income, the production technology is as simple as possible. The only input is human capital and there is constant returns to scale. Hence, the technology for producing good *i* is

(3) $$x(t,i) = \theta(i) h(t,i) \quad \text{for all } i \in \left[0; n(t)\right]$$

where $\theta(i)$ is the productivity level associated with good *i* and $h(t,i)$ is the amount of human capital used to produce good *i* in period *t*.[3]

There is monopolistic competition in the goods market implying that the price is a mark-up over marginal costs:

(4) $$p(t,i) = \frac{1}{\alpha} \frac{w(t)}{\theta(i)} \quad \text{for all } i \in \left[0; n(t)\right].$$

Demand for human capital to produce good *i* is determined by profit maximization as

(5) $$h(t,i) = \frac{\alpha}{w(t)} \frac{\theta(i)^{\varepsilon-1}}{\int_0^{n(t)} \theta(j)^{\varepsilon-1} dj} = \frac{\varepsilon - 1}{w(t)} \frac{\theta(i)^{\varepsilon-1}}{\theta(n(t))^{\varepsilon} - \theta(0)^{\varepsilon}} \quad \text{for all } i \in \left[0; n(t)\right].$$

[3] Decreasing returns to scale does not change the results qualitatively.

The more different types of goods that the economy produces, the less human capital is available for production of each good, and the smaller is the scale of production of each good given productivity. But given the number of different types of goods that is produced in the economy, more human capital is devoted to production of more sophisticated goods than to less sophisticated goods. Hence, at any point in time the scale of production increases with the productivity level due to the constant elasticity of substitution in demand.

The above price rule and human capital demand imply the following instantaneous profit from production of good *i*:

(6)

$$\pi(t,i) = p(t,i)x(t,i) - w(t)h(t,i) = \left(\frac{1-\alpha}{\alpha}\right) w(t)h(t,i) = \frac{1}{\varepsilon} \frac{\theta(i)^{\varepsilon-1}}{\int_0^{n(t)} \theta(j)^{\varepsilon-1} dj} = \frac{\theta(i)^{\varepsilon-1}}{\theta(n(t))^{\varepsilon} - \theta(0)^{\varepsilon}}$$

for all $i \in [0; n(t)]$.

Entrepreneurs

Entrepreneurs may copy and adapt goods invented abroad by allocating human capital to the task of imitation, and there exists an externality effect from imitation activity because each new good adds to the domestic public stock of knowledge. Specifically, it takes $a(t,i) = A\theta(i)^{\varepsilon-1} / n(t)$ units of human capital to imitate good *i* at time *t*. The parameter $A>0$ reflects idiosyncratic characteristics that affect the costs of imitation equally across imitation projects. The larger is *A* the more resources are needed to imitate any good. The idiosyncratic characteristics include the national technological level and efficiency in imitation, economic institutions, government policies and the extent of barriers to technology adoption. Acemoglu (forthcoming) defines economic institutions as the structure of property rights, the presence and functioning of markets and the contractual opportunities available to individuals and firms. All these characteristics may affect the amount of investment an entrepreneur must make to adopt a new technology. Hall and Jones (1999) use a broader concept, social infrastructure, which they define as institutions and government policies that determine the economic environment. Government policies that may affect the value of *A* include business registration fees and other establishment costs. What Parente and Prescott (1994) label technology barriers may also affect the costs of imitation. As examples of barriers, Parente and Prescott mention regulatory and legal constraints, bribes that must be paid, violence or threat of violence, outright sabotage, and worker strikes.

The amount of resources needed to imitate a good is positively correlated with the level of productivity that the good entails reflecting the idea that goods are aligned on a continuum where higher-ranked goods are more sophisticated and, therefore, more costly to imitate. Barro and Sala-i-Martin (1997) treat the cost of imitation as a function of the difference between the number of goods that has been imitated domestically and the number of goods that has been invented worldwide, and they assume that the larger is this difference the smaller are the costs of imitation. The argument could be that it is relatively easier to copy a good when the number of potential targets is larger. Here, the appearance of $\theta(i)$ in the imitation costs function implies the same relationship at a given point in time. It requires fewer resources to imitate goods that are less sophisticated and, therefore, far away from the world technology frontier than to imitate goods that are closer to the frontier.

We also include a knowledge spillover in imitation reflecting that an imitator cannot appropriate all of the potential benefits from his or her imitation effort. In this case, there exists a public knowledge stock that represents a collection of ideas and methods that is useful to later generations of imitators. The size of the knowledge externality at any point in time is measured by the number of differentiated goods that has been imitated until that point in time. Due to this externality effect the model predicts that the amount of resources needed to imitate a certain good decreases over time.

Entrepreneurs can freely enter into the activity of imitation and decide how many goods to copy on the continuous interval between *0* and $\bar{n}(t)$. Let $v(t,i)$ be the value of good *i*. Then value maximization implies that

(7) $v(t,i) = a(t,i)w(t)$ for all goods that are imitated in period *t*.

Once a firm masters the technology that applies to good *i* domestic property rights ensure that it earns an infinite stream of profits from goods production implying the following value of imitating good *i*:

(8) $$v(t,i) = \int_t^{\infty} e^{-\int_t^s r(\tau)d\tau} \pi(s,i)ds .$$

Equation (7) and (8) imply the following no-arbitrage condition which determines a relationship between the cost of imitating a good in period *t* and the present value from production of that good in future periods:

(9) $$\frac{A\theta(i)^{\varepsilon-1}w(t)}{n(t)} = \int_t^{\infty} e^{-\int_t^s r(\tau)d\tau} \pi(s,i)ds$$

where we have used that $a(t,i) = A\theta(i)^{\varepsilon-1}/n(t)$.

Human capital

The total stock of human capital in the economy is determined by the size of the labour force and the education level of the workers:

$$H(t) = L(t)e^{\psi S(t)}$$

where *L(t)* is the number of workers at time *t*, *S(t)* is their average years of schooling and $\psi > 0$ is a constant that measures the private returns to schooling. This specification implies that an extra year of an individual's schooling raises the individual's human capital stock in the same proportion regardless of the level of schooling. With atomistic workers it is also the case that an extra year of an individual's schooling has the same proportional effect on earnings regardless of the level of schooling – a feature that is also present in Mincerian earnings regressions.

We assume that the average years of schooling is determined by government policy and that it is constant over time, $S(t) = S$. Further, we assume that the size of the work force is constant over time, $L(t) = L$.

Equilibrium in the market for human capital implies that the total stock of human capital is allocated between goods production and imitation. From (5) the demand for human capital for manufacturing is

$$n(t)\int_0^{n(t)} h(t,j)dj = \alpha\frac{n(t)}{w(t)}.$$

The amount of human capital devoted to imitation in period *t* is the time derivative of the total amount of human capital allocated to imitation activity until time *t* which is

$$n(t)\int_0^{n(t)} a(j)dj = A\int_0^{n(t)} \theta(j)^{\varepsilon-1}dj = \frac{A}{\varepsilon}\left(\theta(n(t))^{\varepsilon} - \theta(0)^{\varepsilon}\right)$$

The time derivative of this expression is

$$\frac{d}{dt}\left(\frac{A}{\varepsilon}\left(\theta(n(t))^{\varepsilon}-\theta(0)^{\varepsilon}\right)\right)=A\theta(n(t))^{\varepsilon}\frac{\partial\theta(n(t))}{\partial n(t)}\frac{n(t)}{\theta(n(t))}\frac{\dot{n}(t)}{n(t)}.$$

The demand for human capital for imitation depends on idiosyncratic features, the elasticity of substitution of the productivity level with respect to the number of goods $\left(\frac{\partial\theta(n(t))}{\partial n(t)}\frac{n(t)}{\theta(n(t))}\right)$, and the number of goods that is imitated.

Now the condition for equilibrium in the market for human capital becomes:

$$\text{(10)} \qquad \alpha\frac{n(t)}{w(t)}+A\theta(n(t))^{\varepsilon}\frac{\partial\theta(n(t))}{\partial n(t)}\frac{n(t)}{\theta(n(t))}\frac{\dot{n}(t)}{n(t)}=H(t)=Le^{\psi S}$$

4. Steady state and transitional dynamics

Solving the model delivers a difference equation governing the development of *n* (see appendix):

$$\text{(11)} \qquad \dot{n}(t)=\frac{1}{\frac{A}{L}\theta(0)^{\varepsilon}g_{\theta}e^{\varepsilon g_{\theta}n(t)}}\left[e^{\psi S}-\frac{\alpha\rho\theta(0)^{\varepsilon}\frac{A}{L}}{\frac{1-e^{-\rho t^{*}}}{e^{\varepsilon g_{\theta}n(t+c)}-1}+\frac{e^{-\rho t^{*}}}{e^{\varepsilon g_{\theta}\bar{n}}-1}}\right]$$

where we have used that $\theta(i)=\theta(0)e^{g_{\theta}i}$. t^{*} denote the point in time when the economy reaches long-run steady state and $n(t+c)\in(n(t),\bar{n})$ where $\bar{n}$ is the technological capacity limit (for proof of existence and uniqueness of a solution see the appendix). This difference equation determines the development of the number of goods that is imitated and, therefore, the development of productivity over time given the human capital stock, idiosyncratic characteristics and preference parameters.

From (11) the technological capacity limit is determined as

$$(12) \qquad \bar{n} = \frac{\ln\left[1 + \dfrac{e^{\psi S}}{\alpha\rho\theta(0)^{\varepsilon}\dfrac{A}{L}}\right]}{\varepsilon g_{\theta}}.$$

Increases in the average years of schooling, S, and the imitation parameter, A, both have positive and negative effects on the incentives to imitate new goods and, hence, on the technological development. Longer average schooling implies a larger human capital stock which elicits a lower wage rate so that the costs of imitation decrease and imitation activity increases. On the other hand, a larger human capital stock enhances the capacity limit of the economy so that the value of an imitation project decreases because instantaneous profit decreases as the number of goods expands. The positive effect dominates such that a larger human capital stock accelerates imitation activity. Likewise, an increase in imitation costs, A, has a negative effect on the imitation activity but it also lowers the capacity limit of the economy so that the value of an imitation project increases. Here, the negative effect dominates such that a larger value of the imitation parameter is associated with less imitation activity. Since the productivity level of the economy is a continuous positive function of the number of goods that is imitated ($\theta(n(t)) = e^{g_{\theta}n(t)}$) there is a positive relation between the average human capital stock per worker and the steady state productivity level, and a negative relationship between the imitation parameter and the steady state productivity level.

Integrating the manufacturing technology (equation 3) over all goods, substituting the human capital demand from equation 5 and imposing the condition for equilibrium in the market for human capital (equation 10), GDP per worker is determined as

$$(13) \qquad y(t) = \Omega(t)\Theta(t) \text{ where}$$

$$\Omega(t) \equiv e^{\psi S} - \frac{A}{L}\theta(0)^{\varepsilon} g_{\theta} e^{\varepsilon g_{\theta} n(t)} \dot{n}(t) \text{ and } \Theta(t) \equiv \left(\frac{\varepsilon}{\varepsilon+1}\right)\theta(0)\frac{e^{(\varepsilon+1)g_{\theta}n(t)} - 1}{e^{\varepsilon g_{\theta}n(t)} - 1}.$$

$\Omega(t)$ is human capital per worker used in manufacturing while $\Theta(t)$ is a productivity index reflecting that imitation of new goods generates an increase in the productivity level because new goods are more productive than existing ones. The larger is the productivity index and the more human capital per worker is devoted to manufacturing, the larger is GDP per worker.

The capacity limit in (12) implies the following level of GDP per worker in steady state:

(14) $\quad \bar{y} = \bar{\Omega}\bar{\Theta}$ where

$$\bar{\Omega} \equiv e^{\psi S} \text{ and } \bar{\Theta} \equiv \left(\frac{\varepsilon}{\varepsilon+1}\right)\theta(0)\frac{e^{(\varepsilon+1)g_\theta \bar{n}}-1}{e^{\varepsilon g_\theta \bar{n}}-1}.$$

An increase in the average years of schooling implies that there are more human capital available for manufacturing ($\Omega(t)$ increases). Therefore, GDP per worker increases in the short run. There is also more human capital available for imitation so in the longer run the larger imitation activity generates an increase in the average productivity level ($\Theta(t)$ increases) which also affects GDP per worker positively. An increase in the costs of imitation has both a positive and a negative effect on GDP per worker in the short run. First, for a given imitation activity more resources are needed to imitate new goods so human capital available for manufacturing decreases ($\Omega(t)$ decreases given *n(t)* and $\dot{n}(t)$). Second, as it becomes less profitable to imitate, a reallocation of resources away from imitation towards manufacturing takes place ($\Omega(t)$ increases). The positive effect dominates such that GDP per worker increases. In the longer run the lower imitation activity affects average productivity negatively ($\Theta(t)$ decreases) implying a negative relationship between the imitation parameter and GDP per worker in the long run.

The second derivative of the steady state level of sophistication wrt. human capital per worker is negative but the second derivative of steady-state-GDP per worker wrt. human capital is positive. Even though there is constant returns to human capital in the manufacturing technology the fact that more human capital elicits more imitation activity and, therefore, productivity growth implies that the economy uses, on average, a lower and lower amount of human capital to manufacture one unit of output.[4]

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[4] Increasing returns to human capital is a feature that is present in many endogenous growth models, e.g., Romer (1990) and several of the frameworks in Grossman and Helpman (1991). In our framework it is possible to obtain diminishing returns to human capital if we interpret $\left(\int_0^{n(t)} x(\tau, j)^\alpha \, dj\right)^{\frac{1}{\alpha}}$ as a final goods technology and assume diminishing returns to scale in the final goods sector at any moment in time.

While an extra year of schooling has the same proportional effect on earnings regardless of the level of schooling for an individual, the proportional effect of an extra year of average schooling for the economy as a whole depends on the human capital stock in society. The larger is the human capital stock per worker the lower is the semielasticity of GDP per worker wrt. average years of schooling. In a standard Solow model with a Cobb-Douglas production technology and $h = e^{\psi S}$ the semielasticity of GDP per worker wrt. average years of schooling does not depend on the current level of schooling. Bils and Klenow (2000) and Hall and Jones (1999) specify non-linear functional forms in the exponential function in order to generate dependency between the semielasticity and the current level of schooling. We obtain the result by including productivity differentials across goods implying that average productivity depends on the level of schooling because the maximal attainable level of technological sophistication does.

The model is consistent with conditional convergence implying that countries with identical human capital stocks and country-specific characteristics converge towards the same level of income per worker in the long run given by $\bar{y}$. Barro and Sala-i-Martin (1997) were the first to point to the existence of conditional convergence in a model of imitation. In their model the costs of imitation is relatively lower than the costs of inventing new products. Imitating countries, therefore, tend to grow faster than countries that perform research and development (for given government policies and other variables that affect the return from introduction of new products). But as the pool of copiable material decreases, the costs of imitation rises and the growth rate of the imitating country decreases. The costs of imitation, therefore, represent a form of diminishing returns to imitation that is analogous to the diminishing returns to capital accumulation in the neoclassical theory of exogenous technological progress. Here, the growth rate of GDP per worker decreases as the number of differentiated goods increases since more goods lowers the expected profit from imitation activity which slows down the technological development and, thereby, income growth.

5. Numerical simulations

To illustrate further the workings of the model we perform numerical simulations. We assume that (i) the economy is initially far away from steady state implying that $t^* >> t$ (specifically, we assume that t=0 and $t^* = 1000$), and (ii) $n(t+c)$ is a simple average of $n(t)$ and $\bar{n}$. Then the share of human capital employed in imitation is approximately

$$1-\frac{e^{\varepsilon g_\theta\left(\frac{n(0)+\bar{n}}{2}\right)}-1}{e^{\varepsilon g_\theta \bar{n}}-1}$$ and the relationship between A and L is

$$\frac{A}{L}=\frac{e^{\psi S}}{\alpha\rho\theta(0)^{\varepsilon}(e^{\varepsilon g_\theta \bar{n}}-1)}.$$

To determine the values of the parameters we assume that (i) the number of different types of goods produced in the economy initially is 200, (ii) the returns to education is 10%, i.e., $\psi = 0.1$ and (iii) the average years of schooling is 4. By setting $\alpha = 0.58$, $\rho = 8\%$, $g_\theta = 0{,}01\%$ and $\theta(0) = 100$ we obtain a share of human capital used in imitation of 49.3% and a fixed costs of imitation per worker of 0,11%.

Example 1

This example illustrates that two countries with identical human capital stocks may follow different growth paths due to idiosyncratic characteristics. Hence, we consider two countries with identical human capital stocks and initial average productivity levels but the fixed costs of imitation in country 2 are twice the costs in country 1. This difference may be due to lower efficiency, lower quality of institutions, a less business-friendly policy or larger technology barriers in country 2.

Figur 1 shows that the capacity limit of country 1 is almost twice that of country 2. $\bar{n}$ is 1726 in country 1 whereas it is only 951 in country 2. It also illustrates that the annual growth rate of productivity in country 1 exceeds the growth rate in country 2 during the transition since, initially, country 1 is much further away from its capacity limit than country 2 is. The level of GDP per worker is, however, higher in country 2 than it is in country 1 during the first years, cf. figure 2. The reason for this is that, initially, the countries experience the same average productivity in manufacturing but, due to the large costs of imitation in country 2, the productivity of human capital in imitation is relatively low in country 2 compared to country 1. Therefore, country 2 devotes fewer resources to imitation activity implying that more resources are available for manufacturing. In the short run this shows up as a positive effect on GDP per worker but as the productivity level of country 1 expands compared to country 2, GDP per worker in country 1 exceeds that in country 2 after 12 years.

Figure 1. Level of sophistication and capacity limit – example 1

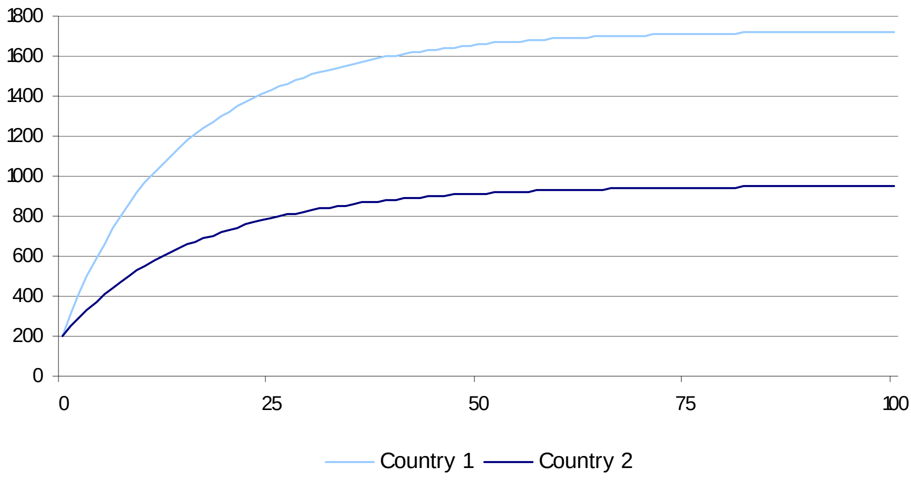
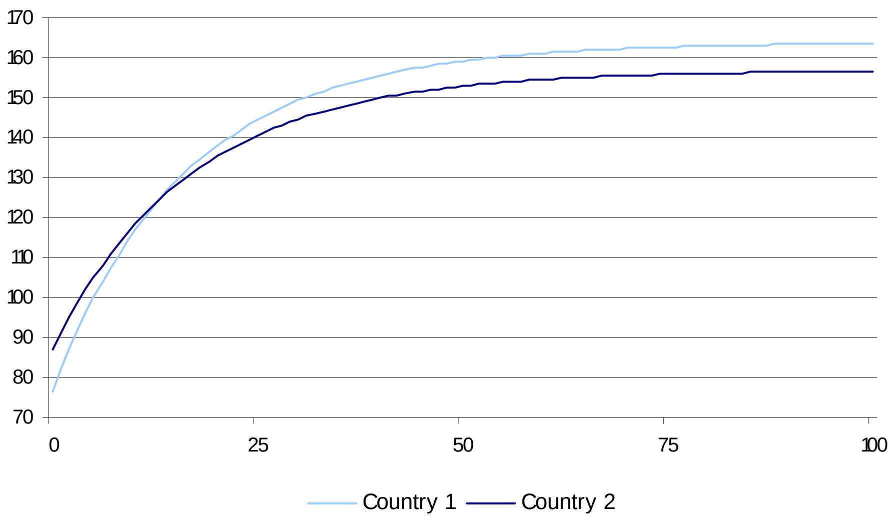


Figure 2. GDP per worker – example 1



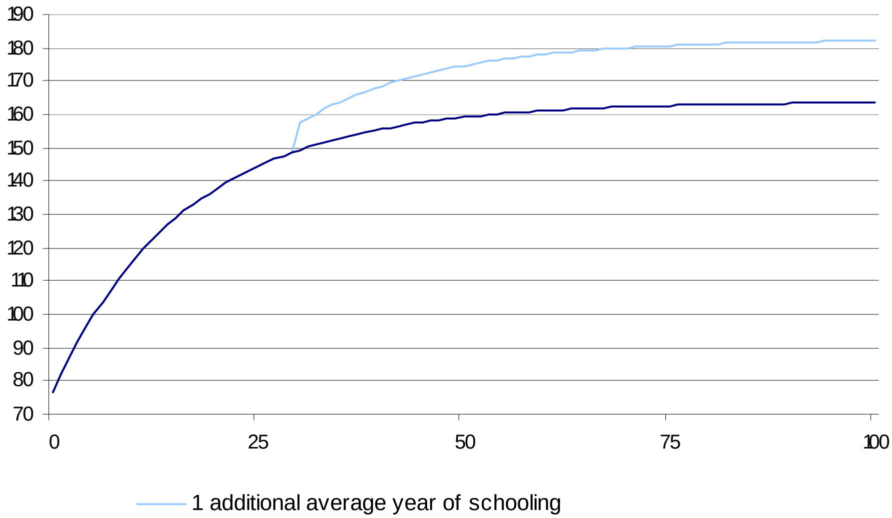
The example illustrates that countries may follow different development paths of income per worker even if the countries are endowed with the same human capital stock due to differences in efficiency, institutions, government policies or technology barriers. The difference may also be interpreted as a cost discovery differential as suggested by Hausmann and Rodrik (2003) and Hausmann et al. (2007). Their idea is that in order to start production of a good for the first time in a developing country an entrepreneur needs to explore the underlying cost structure of the economy. This cost discovery process requires investment of a certain number of units of labour which may be related to our assumption that it takes $A\theta(i)^{\varepsilon-1}/n(t)$ units of human capital to imitate good *i* at time *t*.[5] By constructing a measure of the productivity level associated with countries' specialization patterns, Hausmann et al. find that China (among others) is an outlier in the sense that China's productivity level is much higher than the productivity levels of other countries with approximately the same level of income per capita. Rodrik (forthcoming) suggests that one of the reasons for China's sophisticated export basket is a determined government effort to acquire domestic capabilities and build modern industry. In our model it would imply that the imitation parameter in China is lower than in other countries with a similar endowment of human capital.

Example 2

The second example illustrates the dynamic effects of an increase in the human capital stock and a decrease in the fixed costs of imitation, respectively. In particular, it illustrates that even though the two policies may generate the same long-run development of income per capita, the effects in the short and medium term may differ. We consider a country that manages to increase the average number of years of schooling from 4 to 5 years. For simplicity we assume that it happens during a single period of time. This 25% increase in the average years of schooling causes the human capital stock to expand by 10.5%. Therefore, the capacity limit of the economy goes up from $\bar{n}$=1726 to $\bar{n}$=1873. With a larger human capital stock it is possible to spend more resources on imitation activity *and* on manufacturing. Therefore, GDP per worker increases from the outset with 5.5%. As the effect on average productivity shows up, GDP per worker expands further. After 10 years GDP per worker is 8.3% higher than before the policy change, and in the long run GDP increases by 11.5 %, cf. figure 3.

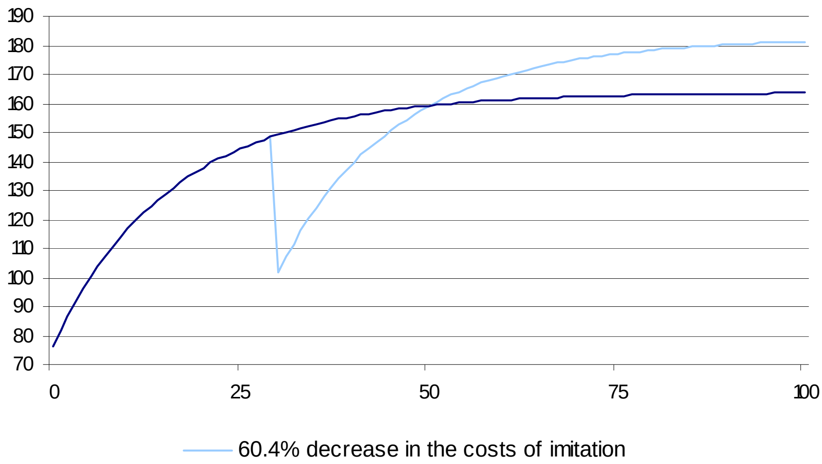
[5] Hausmann et al. (2005) incorporates uncertainty such that entrepreneurs do not know ex ante the productivity level associated with the good that they become able to produce after cost discovery has taken place.

Figure 3. GDP per worker – example 2



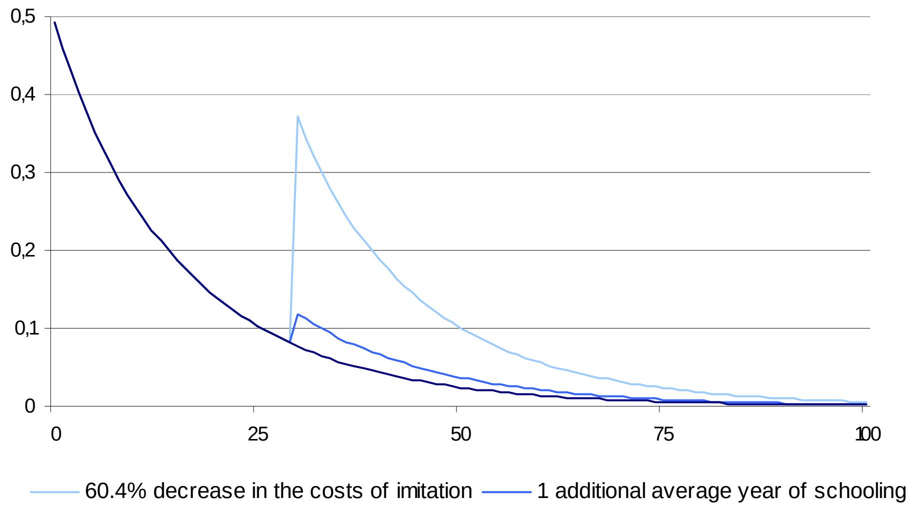
Now, assume that the country chooses to expand its long-run GDP per worker by the same amount by increasing the quality of its institutions or implementing a more business-friendly policy in stead of increasing the average years of schooling. That is, we target the level of GDP per worker in the long run to be the same as in figure 3 and calculate the required change in the imitation paramater to be a decrease of 60.4%. This policy generates short and medium run dynamics which are very different from above, cf. figure 4. GDP per worker immediately drops by 31.9%, after 10 years it is 10.2% lower than it would have been without the policy change, and it takes 21 years before the policy change generates a positive effect on GDP per capita. The reason for this result is that the returns from investment of an extra unit of human capital in imitation increases dramatically when the imitation parameter decreases 60%. Therefore, the share of human capital employed in imitation increases from around 8% to 37% and less resources are available for manufacturing. The cut in the costs of imitation also slows down the convergence towards steady state compared to the increase in the human capital stock. 50 years after the policy changes GDP per worker is 99.2% of the steady state level when the human capital stock increases while it is only 97.7% of the steady state level when the costs of imitation decreases.

Figure 4. GDP per worker – example 2



In conclusion, if the government wishes to increase steady state income per worker and it takes into account the transitional effects then an expansion of the human capital stock is preferable compared to an improvement in its institutions or a more business-friendly policy. But if we consider the technological implications then a reduction in the costs of imitation are preferable to an expansion of the human capital stock. This is because a costs reduction expands the capacity limit of the economy much more than an expansion of the human capital stock does. When the costs of imitation decreases by 60.4% then the number of different types of goods that the economy is capable of producing in the long run doubles. In comparison, one additional average year of schooling only expands the capacity limit by 8.5%. To understand this result look at the effect of the two policies on the human capital split between manufacturing and imitation (figure 5). When the human capital stock increases it affects both manufacturing and imitation because both activities use human capital. But due to the spillover effect in imitation a modest reallocation of human capital away from manufacturing into imitation takes place. When the costs of imitation decrease then the demand for human capital for imitation increases but, initially, there is no change in the demand for human capital for manufacturing. This elicits a huge reallocation of resources away from manufacturing into imitation implying that the economy becomes much more sophisticated when the fixed costs decrease than when the human capital stock expands.

Figure 5. Share of human capital used in imitation – example 2



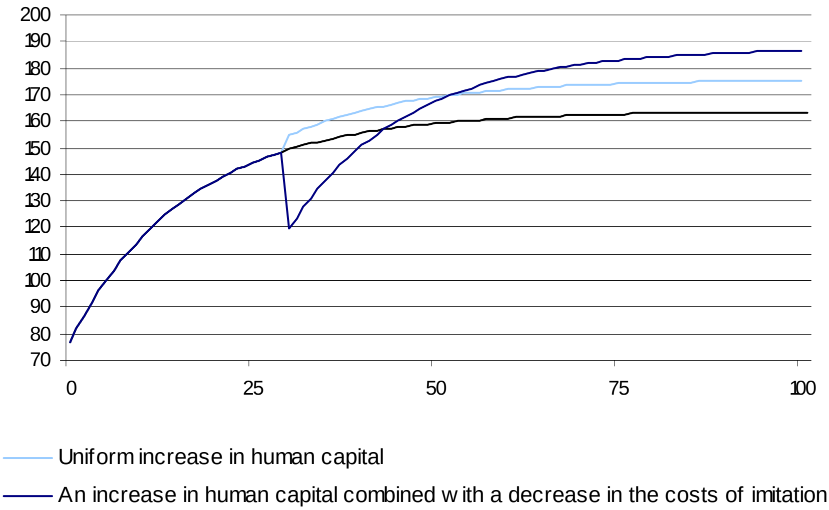
Papaioannou and Siourounis (forthcoming) demonstrate a J-shaped growth pattern following democratization where annual output growth in democratization countries drops significantly during the transition but stabilizes at a higher level in the longer run. Here, the same holds for the dynamic effects of an improvement in institutions or a more business-friendly policy. But while Papaioannou and Siourounis explain the initial negative effect of democratization with the observation that democratizations tend to occur during recessions, the initial drop in GDP per worker in our framework happens as a consequence of a change in the relative costs of imitation compared to manufacturing which affects the incentives to imitate.

Example 3

The last example illustrates the complementarity of human capital and imitation costs and the importance of affecting both to obtain maximal effect on income. Consider an economy where the policymakers implement an education policy that increases average human capital per worker by 0.1 unit (equivalent to an increase in average time spent on education of 0.65 years per worker). The larger human capital stock affects GDP per worker positively because more human capital is available for manufacturing. In the longer run the initial positive effect is supplemented by a positive productivity effect as more human capital is used in imitation which speeds up the technological development. As a consequence GDP per worker increases by 7.3% and the number of different types of goods available increases by 5.4% in the long run.

If, however, imitation costs per worker are lower than human capital per worker then a more effective income generating policy is to substitute part of the human capital increase with an improvement in the quality of institutions. Figure 6 illustrates the case. In stead of limiting the policy focus to education, a mix of education and institutional policies has a larger impact on income. By lowering the costs of imitation by 0.0005 units per worker at the cost of only increasing human capital by 0.0995 units per worker, GDP per worker increases by 14.6% (compared to 6.7% when only human capital is affected). The reason for this result is that the limitation imposed by either of the constraints is relaxed such that the economy is better able to extract the positive effect of either of the policy changes.

Figure 6. GDP per worker – example 3



The above example illustrates the complementarity between human capital accumulation and institutional improvements. A country can develop technologically through ongoing human capital accumulation but if the quality of institutions is not improved then the bad quality limits the technological development possibilities. Likewise, a country can improve the quality of its institutions, thereby increasing the incentives to engage in imitation activity, but if the human capital stock is not increased then the low stock puts an upper limit to the technological development. It is vital for optimal economic development to improve both education facilities and institutions.

6. Conclusions

We have developed a framework that incorporates the idea that goods are associated with different productivity levels and we have analysed the implications in the short and long run. The model is consistent with conditional convergence and the growth path of en economy depends on the size of the human capital stock and idiosyncratic characteristics that affect the costs of imitation. Countries with identical human capital stocks may, therefore, converge towards different long-run levels of income per worker due to idiosyncratic characteristics.

An increase in the average education level and a decrease in the costs of imitation affect the technological development and the level of GDP per worker in the long run positively. It is, therefore, possible to change the development path of income per worker both through policies designed to affect the average education level and through policies designed to affect agents' incentives to engage in imitation activity. Nevertheless, the two policies may have very different effects on income per worker in the short and medium term and on the technological capacity limit.

Our framework implies that GDP per worker is the product of human capital per worker allocated to manufacturing times a productivity index. Both variables depend on the average level of education in the economy and the fixed costs of imitating. Hence, changes in the education level affect the development path of the economy both through its effect on the resources available for production and through its effect on the productivity index. This feature has implication for empirical growth analyses. Often growth empirics start from a Cobb-Douglas production technology with labour, human capital and physical capital. Then the growth rate of GDP per worker is a linear function of population growth, human capital growth, physical capital growth and productivity growth. Our analysis suggests that it is important to take account of the effect that changes in average education has both on the human capital accumulation *and* the productivity growth. By excluding the latter effect the analysis underestimates the effect of education on per-worker-GDP growth. This feature of the model may contribute to explain the low and often insignificant estimate found when regressing growth in income per capita on human capital accumulation.

Our model could be extended in several dimensions. First, the innovation of new goods takes place abroad and we do not model the innovation activity. In reality, a combination of imitation and innovation drives total factor productivity. A further step could, therefore, be to study the interaction between human capital and idiosyncratic characteristics when both activities are modelled explicitly. Second, our numerical examples illustrate the existence of different dynamic effects of education policies and policies designed to affect imitation activity. Including some lags in the human capital accumulation process would ensure more rigorous dynamic effects. Third, international trade considerations would make it possible to study the dynamic interaction between human capital and idiosyncratic characteristics in the context of international specialization.

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Appendix

Substituting equations (2’), (6) and (10) into equation (9) delivers the following expression

$$\text{(A1)} \qquad \dot{n}(t) = \frac{1}{A\theta(0)^{\varepsilon} g_{\theta} e^{\varepsilon g_{\theta} n(t)}} \left[Lh - \frac{\alpha A\theta(0)^{\varepsilon}}{\int_0^{\infty} \frac{e^{-\rho s}}{e^{\varepsilon g_{\theta} n(t+s)} - 1} ds} \right].$$

Equation (A1) is an ordinary difference equation of 1st order that depends on one variable only. It has the general form $\dot{x} = F(t, x)$. It is not possible to calculate a solution analytically. In stead we use qualitative theory to proof the existence and uniqueness of a solution.

Let $x(t) \equiv e^{-\varepsilon g_{\theta} n(t)}$ then

$$F(t, x) = \frac{1}{A\theta(0)^{\varepsilon} g_{\theta}} x(t) \left[Lh - \frac{\alpha A\theta(0)^{\varepsilon}}{\int_0^{\infty} e^{-\rho s} \frac{x(t+s)}{1 - x(t+s)} ds} \right].$$

Since $F(t, x)$ and $F_x'(t, x)$ are continuous for *n>0* there exists one and only one solution to the difference equation (A1) with an associated integral curve that passes through (t_0, x_0).[6]

To determine the development of the economy during the transitional period it is noted that when there exists a steady state with a constant number of differentiated goods then the integral

$$\int_0^{\infty} \frac{e^{-\rho s}}{e^{\varepsilon g_{\theta} n(t+s)} - 1} ds$$

in (A1) may be split up in two integrals. Let t^* denote the point in time when the economy reaches long-run steady state. Before t^* there is positive growth in *n*, and from time t^* on the number of differentiated goods is constant. Hence,

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[6] Sydsæter (1986), p. 21.

$$\int_0^{\infty}\frac{e^{-\rho s}}{e^{\varepsilon g_\theta n(t+s)}-1}ds=\int_0^{t^*}\frac{e^{-\rho s}}{e^{\varepsilon g_\theta n(t+s)}-1}ds+\int_{t^*}^{\infty}\frac{e^{-\rho s}}{e^{\varepsilon g_\theta n(t+s)}-1}ds=\int_0^{t^*}\frac{e^{-\rho s}}{e^{\varepsilon g_\theta n(t+s)}-1}ds+\frac{1}{e^{\varepsilon g_\theta \bar{n}}-1}\int_{t^*}^{\infty}e^{-\rho s}ds$$

$$=\int_0^{t^*}\frac{e^{-\rho s}}{e^{\varepsilon g_\theta n(t+s)}-1}ds+\frac{1}{\rho}\frac{e^{-\rho t^*}}{e^{\varepsilon g_\theta \bar{n}}-1}=\frac{1}{\rho}\left(\frac{1-e^{-\rho t^*}}{e^{\varepsilon g_\theta n(t+c)}-1}+\frac{e^{-\rho t^*}}{e^{\varepsilon g_\theta \bar{n}}-1}\right)$$

where $n(t+c)$ is between $n(t)$ and $\bar{n}$, and we have used the generalized mean value theorem.[7] By substituting this expression into (A1) we can determine the development of *n* during the period $t\in[0,t^*)$:

(A2) $$\dot{n}(t)=\frac{1}{\frac{A}{L}\theta(0)^{\varepsilon}g_\theta e^{\varepsilon g_\theta n(t)}}\left[e^{\psi S}-\frac{\alpha\rho\theta(0)^{\varepsilon}\frac{A}{L}}{\frac{1-e^{-\rho t^*}}{e^{\varepsilon g_\theta n(t+c)}-1}+\frac{e^{-\rho t^*}}{e^{\varepsilon g_\theta \bar{n}}-1}}\right]$$

and *n* in steady state:

(A3) $$\bar{n}=\frac{\ln\left[1+\frac{e^{\psi S}}{\alpha\rho\theta(0)^{\varepsilon}\frac{A}{L}}\right]}{\varepsilon g_\theta}.$$

Equations A2 an A3 corresponds to equations 11 and 12 in the text

[7] The generalized mean value theorem states that $\int_a^b f(x)g(x)dx=f(c)\int_a^b g(x)dx$ where $c\in[a,b]$. It is valid if $f(x)$ and $g(x)$ are continuous in $a\le x\le b$.

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